A FRAMEWORK FOR ASSESSING AND REPORTING ON ECOLOGICAL CONDITION

INTRODUCTION

A wealth of environmental monitoring information has been developed since the nation first turned its collective attention to improving environmental quality more than three decades ago. Yet many scientists, most decision-makers, and nearly all members of the public still have little understanding of the "health" or integrity of the nation's ecological systems. The monitoring programs tailored to report on the implementation of environmental laws and programs -- the cleanup of pollutants, the management of public forests and rangelands, and so forth – accomplish the intended purpose but do not provide the information required to assess the integrity of ecological systems in a systematic way across regions.

Recognizing this information gap, a special panel of the EPA Science Advisory Board has developed a sample framework for assessing and reporting on ecological condition at a local, regional, or national scale. The sample framework is intended as an organizing tool that may help the Agency decide what ecological attributes to measure and how to aggregate those measurements into an understandable picture of ecological integrity.

Environmental reporting usually draws upon a range of measures, from those that capture agency activities to those that provide information about ecological integrity or human health. In addition, reports can focus on economic benefits derived from ecosystems (such as flows of goods and services), or on the condition of human health or ecological resources irrespective of whether quantifiable economic benefits are produced. In this report, the Panel focuses exclusively on condition measures related to ecological integrity or condition because these are a critical -- and largely missing-- link in the information base upon which environmental reporting can be built.

REPORTING ARCHITECTURE

In order to foster consistent and comprehensive assessment and reporting on the condition of ecological resources, the Panel proposes a framework in which information on generic ecological characteristics can be measured, logically assembled, then synthesized into a few, scientifically defensible categories. Information from these categories can then be excerpted to report on a variety of environmental management goals. This framework for consolidating information can be used as part of a reporting system (Figure 1) that contains the following major elements:

Goals and Objectives. Ideally, environmental management programs begin with a process to develop goals and objectives that articulate the desired ecosystem conditions that will result from the program(s). Methods to develop and use goals and objectives for environmental management have been developed extensively elsewhere and are not part of this report.

Essential Ecological Attributes. The Panel proposes a set of six Essential Ecological Attributes (EEAs) that together define the condition of ecological systems. The EEAs and their component categories and subcategories (Table 1) can be used as a checklist to help design environmental management and assessment programs and used as a guide for aggregating and organizing information. The elements of the table and its hierarchical organization are derived from a conceptual

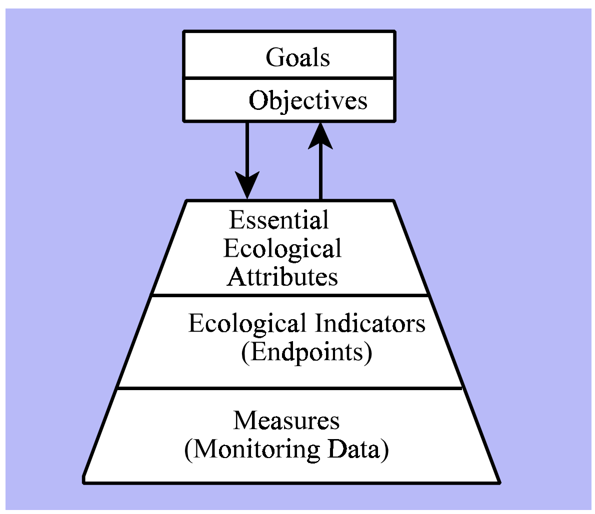


Figure 1. Proposed Architecture for Assessing and Reporting on Ecological Condition.

model of ecological system pattern and process, and incorporate ecological structure, composition, and function at a variety of scales.

Ecological Indicators. Ecological indicators (also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of ecological systems. Multiple indicators may be associated with each subcategory in the EEA hierarchy.

Measures. The measures are specific monitoring variables that are measured in the field and aggregated into one or more ecological indicators (or endpoints).

The relationship among these components is relatively straightforward. Measures (monitoring data) are aggregated into ecological indicators. Indicators are aggregated into the subcategories of the hierarchy of EEAs. In theory, therefore, the framework provides a mechanism to display the relationship between monitoring data or indicators and the overarching conclusions that can be drawn about the condition of various important ecological attributes.

Figure 1 shows a clear separation between goals and objectives in the upper half and EEAs, indicators, and measures in the lower half, to emphasize that EEAs are a function of the ecological systems of interest and are not derived from the goals and objectives. The EEAs are designed to apply generically – that is, to most aquatic and terrestrial systems at the local, regional, or national scale. The independence of the EEA hierarchy from specific management objectives is what makes it amenable to consistent application across many different regions and types of programs. This independence does not mean that the EEAs and objectives are unrelated, however. The EEAs provide an organized body of information from which one can assess a program's success in meeting <u>any</u> set of objectives relating to ecological condition. In other words, a performance measure related to a specific objective of an environmental program will draw information from a unique subset of the EEAs.

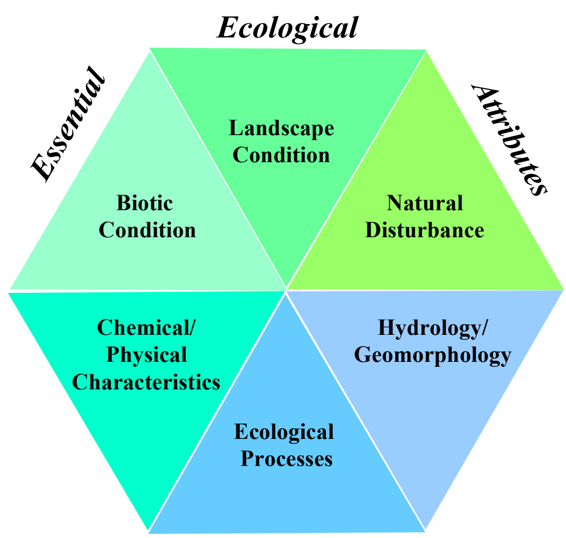


Figure 2. Essential attributes that define ecological systems

ESSENTIAL ECOLOGICAL ATTRIBUTES

The EEAs in Figure 2 divide up the universe of information that describes the state of an ecological system in a logical manner that is solidly grounded in current scientific understanding. The EEAs include three ecological attributes that are primarily "patterns" (Landscape Condition, Biotic Condition, and Chemical/Physical Characteristics) and three that are primarily "processes" (Hydrology/Geomorphology, Ecological Processes, and Natural Disturbance). Describing ecological systems in terms of pattern and process has a long history in ecological science and has been a useful construct for many years. In a nutshell, the processes create and maintain patterns, which consist of the elements in the system and the way they are arranged; these patterns in turn affect how processes are expressed (e.g., a riparian forest's effect on river flow and velocity).

In order to subdivide pattern and process into EEAs, the Panel elected to highlight ecological characteristics that often are overlooked by the Agency and by members of the public (such as landscape structure, natural disturbance, and ecological processes). For ease of use, the Panel grouped characteristics that generally are measured together. The EEAs and their component categories and subcategories are summarized below and in Table 1.

Table 1. Essential Ecological Attributes and Reporting Categories

Landscape Condition
- Extent of ecological system/habitat types
- Landscape Composition
- Landscape Pattern and Structure

Biotic Condition
- Ecosystems and Communities
  - Community Extent
  - Community Composition
  - Trophic Structure
  - Community Dynamics
  - Physical Structure
- Species and Populations
  - Population Size
  - Genetic Diversity
  - Population Structure
  - Population Dynamics
  - Habitat Suitability
- Organism Condition
  - Physiological Status
  - Symptoms of Disease or Trauma
  - Signs of disease

Chemical and Physical Characteristics (Water, Air, Soil, and Sediment)
- Nutrient Concentrations
  - Nitrogen
  - Phosphorus
  - Other Nutrients
- Trace Inorganic and Organic Chemicals
  - Metals
  - Other Trace Elements
  - Organic Compounds
- Other Chemical Parameters
  - pH
  - Dissolved Oxygen
  - Salinity
  - Organic Matter
  - Other
- Physical Parameters

Ecological Processes
- Energy Flow
  - Primary Production
  - Net Ecosystem Production
  - Growth Efficiency
- Material Flow
  - Organic Carbon Cycling
  - N and P Cycling
  - Other Nutrient Cycling

Hydrology/Geomorphology
- Surface and Groundwater flows
  - Pattern of Surface Flows
  - Hydrodynamics
  - Pattern of Groundwater Flows
  - Salinity Patterns
  - Water Storage
- Dynamic Structural Characteristics
  - Channel/Shoreline Morphology, Complexity
  - Extent/Distribution of Connected Floodplain
  - Aquatic Physical Habitat Complexity
- Sediment and Material Transport
  - Sediment Supply/Movement
  - Particle Size Distribution Patterns
  - Other Material Flux

Natural Disturbance Regimes
- Frequency
- Intensity
- Extent
- Duration

Landscape Condition

A landscape is an area composed of a mosaic of interacting ecosystems, or habitat patches. Habitat condition may reflect both abiotic features (e.g., elevation, proximity to water) and biotic features (e.g., dominant species, presence of predators). A change in the size and number of natural habitat patches, or a change in connectivity between habitat patches, affects the probability of local extinction and loss of diversity of native species and can affect regional species persistence. Patch heterogeneity also affects both biotic and abiotic landscape processes. Thus, there is empirical justification for managing entire landscapes, not just individual habitat types, in order to insure that native plant and animal diversity is maintained. The Panel recommends that landscape indicators be reported in the following three categories:

Extent. The areal extent of each habitat type within a landscape is important because a decrease in the total area of habitat available often is correlated with species decline. Extent may be reported for broad land cover classes, for finer subunits, or both.

Landscape Composition. Landscape composition can be measured by several metrics, including the number of landcover/habitat types, the number of patches of each habitat, and size of the largest patch (because populations are unlikely to persist in landscapes where the largest patch is smaller than that species' home range).

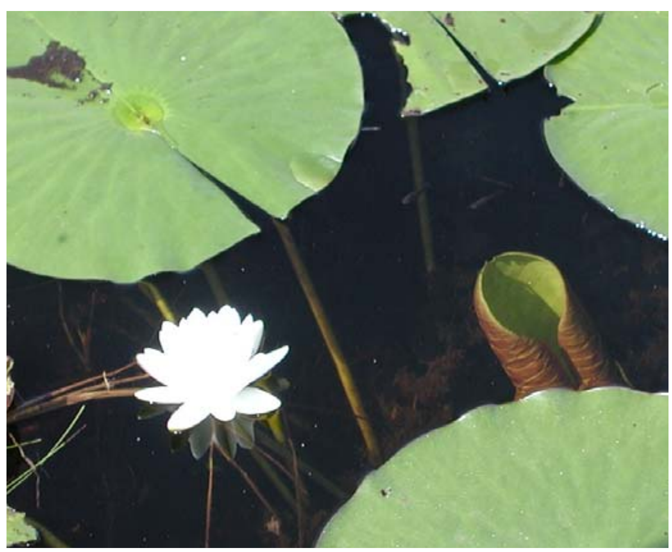
Landscape Pattern/Structure. The spatial pattern of habitat affects population viability of native species. Recent advances in remote sensing and geographic information systems (GIS) allow indices of pattern to be applied over large areas.

Biotic Condition

For this reporting framework, the Panel defines biotic condition to include structural and compositional aspects of the biota below the landscape level (i.e., for ecosystems or communities, species/populations, individual organisms, and genes). Within these biological levels of organization, measures of composition (e.g., the presence or absence of important elements, and diversity) and structural elements that relate directly to functional integrity (such as trophic status or structural diversity within habitats) are considered.

Ecosystem or Community Measures. An ecological community is the assemblage of species that inhabit an area and are tied together by similar ecological processes (e.g., fire, hydrology), underlying environmental features (e.g., soils, geology) or environmental gradients (e.g., elevation, temperature), and form a cohesive, distinguishable unit. In this framework, community measures are divided into subcategories that are consistent with the concept of "biotic integrity" as defined by Agency guidance on biological assessment and biological criteria.

Species or Population Level Measures. Measures of the condition or viability of populations of species in an area are important indicators, yet monitoring the status of all species is impossible from a practical standpoint. To address this problem, a higher taxonomic level can be used, or a subset of species called focal species can be monitored. Focal species are selected because they exert a disproportionately important influence on ecosystem condition or provide information about the ability of the system to support other species. In addition, some species (such as endangered, rare, sensitive, and game species) require attention because they are of direct interest to



society.

Individual Organism Measures. Whereas the preceding categories of biotic condition are concerned largely with system, community, or population level measures, there are instances when the health of particular individuals (e.g., for focal species or for species imperiled or vulnerable to extinction or extirpation from an area) may be of interest. In addition, the health of individuals may presage an effect on a population or related ecological process (e.g., the presence of life-threatening birth defects in an animal population, or symptoms of disease in a forest).

Chemical and Physical Characteristics (of Water, Air, Soil, and Sediment)

The characteristics included here are measures of chemical substances that are naturally present in the environment and physical parameters (such as temperature and soil texture). These environmental attributes have received substantial public attention and monitoring because they are the subject of pollution control laws (e.g., the Clean Air Act, Clean Water Act, and the like). The categories listed below may be reported separately for air, for water, and so forth. Alternatively, categories can be used to display integrated information from all environmental compartments (air, water, soil, and sediment) at once.

Nutrient concentrations. Nutrients are those elements required for growth of autotrophic organisms, whose ability to produce organic matter from inorganic constituents forms the ultimate base of food webs. Concentrations of nutrients, including phosphorus, nitrogen, potassium, and micronutrients (e.g., copper, zinc, and selenium) may be limiting if available in too small a quantity or may lead to undesirable consequences if present in too great a quantity.

Trace inorganic and organic chemicals. Baseline information about concentrations of metals and organic chemicals (whether or not their concentrations are altered by pollutant discharges) provides a foundation for assessing their ecological significance.

Other chemical parameters. Other chemical parameters that should be reported will differ depending on the environmental compartment (water, air, soil, and/or sediment) being assessed. In soils and sediments, for example, measures such as total organic matter, cation exchange capacity, and pH will be important.

Physical parameters. Physical measures, such as air and water temperature, wind velocity, water turbidity, and soil bulk density, complement the measures of physical habitat contained in other EEAs.

Ecological Processes

For this reporting framework, the Panel defines ecological processes as the metabolic functions of ecosystems – energy flow, elemental cycling, and the production, consumption and decomposition of organic matter. Biotic processes (which are included under biotic condition for convenience), also could be included here. Many of the ecological process indicators are taken from *Ecological Indicators for the Nation*, recently published by the National Research Council. The Panel stresses, as did NRC, that adequate indicators are not yet available for all of the key attributes of energy and material flows in ecosystems.

Energy Flow. The most basic ecosystem attribute, fundamental to life on earth, is ecosystem productivity, or the ability to capture sunlight and convert it to high energy organic matter (biomass), which supports the non-photosynthetic trophic levels, including grazers, predators, and decomposers. The balance among production, consumption and decomposition defines the efficiency of an ecosystem and its ability to provide the goods and services upon which society depends.

Material Flow. Biogeochemical cycles that are key to ecosystem function include cycling of organic matter and inorganic nutrients (e.g., N, P and micronutrients such as selenium and zinc). Material and energy flow are linked processes and many indicators provide information on both.

Hydrology/Geomorphology

The hydrology and geomorphology of ecological systems reflect the dynamic interplay of water flow and landforms. In river systems, for example, water flow patterns and the physical interaction among a river, its riverbed, and the surrounding land determine whether a naturally diverse array of habitats and native species are

maintained.

Water Flow. Surface and groundwater flows determine which habitats are wet or dry and when, and water flows transport nutrients, salts, contaminants, and sediments. The variability of water flows (in addition to their timing and magnitude) also exerts a controlling influence on the creation and succession of habitat conditions.

Dynamic structural characteristics. Structural characteristics in streambeds (or lakebeds or bottom terrain of estuaries) and banks (or shoreline) are maintained by water flows and sediment movement. Accordingly, measures of dynamic structural characteristics reflect the integrity of these processes and provide direct information about the quality and diversity of habitats. Characteristics included in this category include channel morphology and shoreline characteristics, channel complexity, distribution and extent of connected floodplain, and aquatic physical habitat complexity.

Sediment and other material transport. A wide variety of underwater and near-shore habitats is maintained by the pattern of sediment and debris movement. Native species have adapted accordingly; for example, many anadromous fish require clean gravels for spawning, and invertebrates choose particular particle sizes for attachment or burrowing.

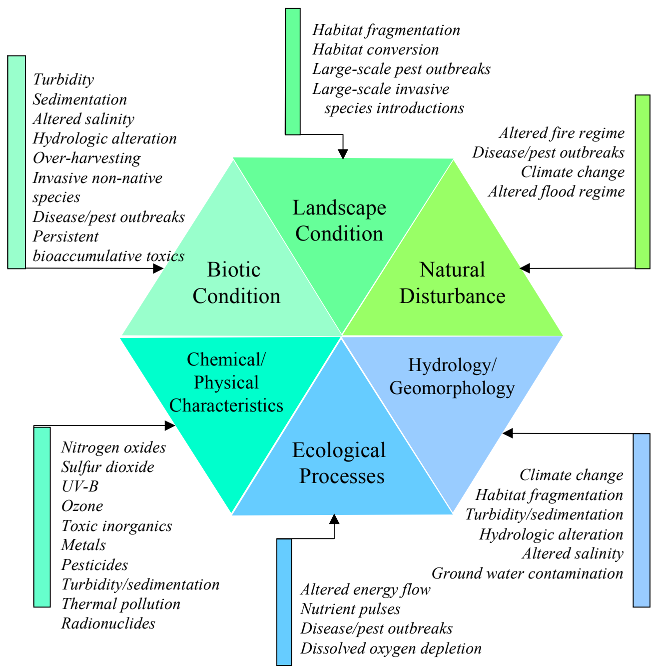


Figure 3. Example stressors and EEAs often affected.

NATURAL DISTURBANCE REGIMES

All ecological systems are dynamic, due in part to discrete and recurrent disturbances that may be physical, chemical, or biological in nature. Examples of natural disturbances include wind and ice storms, wildfires, floods, drought, insect outbreaks, microbial or disease epidemics, invasions of nonnative species, volcanic eruptions, earthquakes and avalanches. The frequency, intensity, extent, and duration of the events taken together are referred to at the "disturbance regime." Each of the disturbance regimes that is relevant to the ecological system should be included in the assessment.

THE ROLE OF STRESSOR INDICATORS

In practice, reports about ecological condition often indiscriminately mix condition indicators with indicators of stressors such as pollution. The framework presented here distinguishes between ecological condition indicators and indicators of anthropogenic stressors, and the EEAs relate only to condition. This approach is consistent with that of the National Research Council (2000) and The Heinz Center (1999). Often, however, the goals of environmental programs relate to the management of stressors (such as pollutants or habitat alteration). In these programs, reporting on the achievement of objectives will involve assessment of ecological condition, an assessment of stressors, and the relationship between the two. The correlation between condition indicators and stressor indicators is not one-to-one: many stressors affect a single condition attribute; and many condition attributes are affected by a single stressor (Figure 3). Assessment of ecological condition, therefore, shows the effects of multiple stressors acting at once and can highlight unforeseen effects. The SAB framework can be adapted to incorporate parallel information on stressors for this purpose. In addition, the array of ecological attributes shown in Table 1 can be used as a checklist to identify components that should be addressed in ecological risk assessments.

APPLYING THE FRAMEWORK

Designing an ecological condition assessment. One purpose of the EEA hierarchy (Table 1) is to provide organizational structure for the process of selecting ecological system characteristics that will be assessed. The Panel recommends beginning with a rebuttable presumption that all of the entries in Table 1 will be included. A "thought experiment" can then be conducted to eliminate the subcategories and categories that are not relevant to the assessment. When resources are limiting, the Panel generally recommends limiting the number of subcategories for which data are collected, rather than eliminating an entire category. Similarly, it may be preferable to limit the number of categories assessed rather than eliminating an entire EEA.

Following the initial selection of EEA categories and subcategories, a series of checks should be undertaken to assure that the selections accomplish the intended goals and are scientifically defensible. For example, the list should be analyzed to assure that its components are sufficient to address any goals and objectives that have been developed for management of the ecological system. Similarly, components of the list should be sufficient to address questions of known public interest (such as the preservation of economically valuable species or the sustainability of patches of old-growth forest). If the list falls short, then additional indicators may be added. The final product of this design process should not only describe the assessment and reporting scheme, but also transparently record the decision tree and professional judgments used to develop it.

Creating a Report. Effective reporting on ecological condition requires policy judgments and scientific understanding (to determine what to report), and it requires communications expertise (to determine how to report it). Here, the Panel addresses only the scientific issues.

The SAB framework provides a scientifically derived scheme for combining hundreds of different indicators into a few ecologically related categories for reporting. Using Table 1 as a guide, the information from an array of indicators can be grouped into a single subcategory and – if desired – collapsed into a single quantitative or qualitative entry. The information within subcategories can then be aggregated into a single category, and so forth. The discovery that some categories lack data also is important information for both decision-makers and the public.

Depending on the level of interest and expertise of the audience, reports can be issued at the level of individual indicators, subcategories, categories, EEAs, or the ecological system as a whole. Many reports combine several levels of reporting. If the objective of the report is to provide information on ecosystem integrity and sustainability, then the EEAs can be used as reporting units (i.e., a "score" or qualitative assessment would be presented for each EEA). The concepts behind the EEAs are fairly straightforward; for non-technical audiences, the presentation would benefit from conversion into lay language. For example, hydrology and geomorphology might become a description of "water flows and riverbanks" for a river basin report.

Alternatively, the information that has been aggregated into EEAs and categories can be extracted in order to report on a particular management objective. For example, an objective such as "protect functional habitat types throughout the watershed" might use the extent category of Landscape Condition to report directly on the amount of each habitat currently in existence. In addition, a consolidated "indicator" that incorporates the Hydrology/Geomorphology, Disturbance, Ecological Processes, and Landscape Condition EEAs might be used to report whether these habitats are functional and likely to be maintained into the future.

The process of aggregating information from multiple indicators into a single entry for reporting – even following the template in Table 1 – involves nontrivial scientific judgments. An expansive scientific literature is available to determine appropriate methods for creating indices and aggregating measures into endpoints, endpoints into categories, and so forth.

Interpreting Indicator Values. To make the proposed reporting framework operational, reference conditions should be defined against which measured values for indicators can be compared. The reference conditions are helpful for interpreting results and are required in order to determine how results can be normalized (qualitatively or quantitatively) for aggregation. This normalization procedure allows various indicators to be collapsed into one result, and it allows results from different regions to be compared. The Panel recommends that the Agency support current efforts to develop reference conditions for this purpose.

EXAMPLE APPLICATIONS OF THE FRAMEWORK

To illustrate the proposed framework's application to programs at different geographic scales and with different objectives, as well as to check the completeness of the framework, the Panel selected four environmental reporting programs as case examples: an Office of Research and Development program designed to assess condition of ecological systems; a USDA Forest Service program designed to assess forest condition nationwide; the Office of Water's Index of Watershed Indicators (IWI), designed to convey information to the public about watershed condition; and a joint EPA-state reporting program designed to track progress meeting environmental goals. The Panel, along with representatives of the programs, reviewed these case studies to determine whether components should be added to the framework, whether the framework provided a useful checklist for the program, and whether the framework provided a reasonable way to organize and report on the program's indicators. The results of these road tests are summarized in the Panel's full report.

CONCLUSIONS

Assessing ecological system condition. In every example program tested by the Panel, the list of Essential Ecological Attributes and associated subdivisions proved useful. In all cases, use of the EEA hierarchy as a checklist highlighted missing elements – elements representing ecological system characteristics broad enough in scope and importance to affect the achievement of the programs' objectives. Recognizing that resources are always limited and that expanding a program is often infeasible, the EEA checklist provides a method to analyze the tradeoffs inherent in choosing which characteristics to address. The fact that the checklist is organized hierarchically allows the user to determine whether major characteristics (e.g., the entire array of hydrology and geomorphology characteristics) are being eliminated from consideration in favor of a cluster of closely-related attributes (e.g., every subcategory and indicator of biotic condition at the community level).

In the Panel's experience, the ecological attributes commonly omitted by Agency programs are those outside the realm of biotic condition and chemical and physical characteristics. This pattern has been noted by the SAB in the past and it is an understandable outgrowth of the issues targeted by the Agency's legal mandates. A more complete look at ecological characteristics is key, however, to allow the Agency to: analyze correctly the causes of environmental degradation; effectively target corrective actions; and help address environmental problems across large geographic areas such as watersheds.

Another benefit of the EEA hierarchy is to provide a logical method for grouping ecologically related elements across system types (such as forests, rangelands, and aquatic systems) and/or across programs that have different legal mandates. This feature can be used when the Agency addresses problems that span different "media" (i.e., water, air and land) in order to provide environmental protection for watersheds and other geographic units. It also can be used as a unifying framework on which to map various types of ecological assessment activities within the Agency. There is clear justification for a variety of different programs with different purposes to exist within the Agency, among other federal agencies, and in the private sector for the purpose of assessing ecological condition. This diversity brings strength and depth to our understanding. It does not, by itself, insure that efficiencies among programs are realized, that deficiencies in programs are addressed, or that the information from one assessment is used to enhance the understanding gained from other studies. Tools such as the SAB framework – which provide a consistent template for assessing the condition of ecological systems -- could be used to foster greater integration, a higher quality of ecological assessment, and increased efficiency among Agency programs. It also could be used to assist the Agency to become a locus for integrating information from different government agencies.

Reporting on ecological system condition. One

major purpose of this framework and EEA list (Table 1) is to help avoid common reporting problems. First, report authors often discover that there are numerous relevant ecological indicators, yet there is little guidance available about how they should be distilled into a few scientifically credible indicators for the public. Faced with this problem, many report authors select a small subset of indicators they judge to be important. Although the reasoning may be sound (e.g., select indicators that are of interest to the public), the resulting report often appears to be a disjointed collection of facts that does not adequately characterize ecological condition or effectively address other goals developed by society for ecosystem management. Second, many report authors confine their reporting to information that is readily available. Yet, most easily accessible information (e.g., water quality data regarding chemical contaminants) is related to past problems and is only part of the information required to predict future problems or manage the ecosystem. This approach also reinforces a somewhat circular public policy: people care about what they learn about via reports; and reports contain information that the authors think people care about. Information that might lead to more informed decisions – wherein protective or corrective actions are targeted at the most important problems – may be left out of this circular loop.

The framework presented here can help avoid these problems by providing a roadmap for grouping monitoring data and indicators into scientifically defensible categories that directly relate to important characteristics of ecological condition. These categories are straightforward, and they can therefore be explained to decision-makers, legislators, and the public. (The language used by the Panel would not, however, be suitable for this purpose. Translation into lay language would be required.)

When the purpose of a report is to address questions of particular interest to the public or address ecosystem management goals that have been developed with public input, the SAB framework provides a way to organize information that can then be extracted for reporting. For example, a "report card" entry on the health of native habitats, plants, and animals would draw from the information aggregated into the landscape condition and biotic condition EEAs. A companion report card entry on the ability of the ecosystem to sustain healthy plants and animals into the future would add information from each of the remaining EEAs. In some cases, however, the SAB framework does not work well for organizing indicators into a report. One example would be a regional water quality report for which data will be drawn from monitoring programs designed specifically for that purpose. In this example, the SAB framework is better used as an analytical tool than a report outline.

In sum, the Panel finds that the proposed framework accomplishes its intended purpose. The framework provides a checklist that can help identify the ecological attributes that are important to assess in order to evaluate the health or integrity of ecological systems. It also provides an organizational scheme for assembling hundreds of individual parameters into a few understandable attributes. Ecological systems are complex, and it has proved extremely difficult to answer the holistic questions that people ask about them – "How healthy is my watershed? Will native species be here for my children and grandchildren to enjoy?" With this report, we provide a way to integrate scientific data into the information necessary to answer these questions, and ultimately to foster improved management and protection of ecological systems.

The Panel's full report, A Framework for Assessing and Reporting on Ecological Condition, can be found at www.epa.gov/sab/xxx

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